Naval Research Laboratory
Stennis Space Center, MS 39529-5004

NRL/FR/7441--94-9604

A Comparison of the Compressed Aeronautical Chart and Compressed ARC Digitized Raster Graphics Compression Techniques for ARC Digitized Raster Graphics Compression

RUTH A. GUIDRY
KEVIN B. SHAW

Mapping, Charting, and Geodesy Branch
Marine Geosciences Division

July 14, 1995

REPORT DOCUMENTATION PAGE

Form Approved
OBM No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
July 14, 1995

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
A Comparison of the Compressed Aeronautical Chart and Compressed ARC Digitized Raster Graphics Compression Techniques for ARC Digitized Raster Graphics Compression

5. FUNDING NUMBERS

Job Order No.	574559505
Program Element No.	0603704N
Project No.	R1987
Task No.	300
Accession No.	DN257086

6. AUTHOR(S)
Ruth A. Guidry and Kevin B. Shaw

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Research Laboratory
Marine Geosciences Division
Stennis Space Center, MS 39529-5004

8. PERFORMING ORGANIZATION REPORT NUMBER
NRL/FR/7441--94-9604

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Research Laboratory
Marine Geosciences Division
Stennis Space Center, MS 39529-5004

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This study compares two Defense Mapping Agency databases, the Navy Standard Compressed Aeronautical Chart (CAC) database and the Air Force Compressed Equal Arc-second Raster Chart Digitized Raster Graphics (CADRG) database, that are made up of compressed ARC digitized raster graphics data. There continues to be a large demand for raster map data in both the Department of Defense and commercial communities. Attention is focused on the various algorithms used to implement the compressions for each database. Both databases follow the same three basic steps, although the CADRG database employs some filtering techniques as well. Results show that the CADRG database, which achieves a 55:1 compression, outputs images that are slightly sharper, clearer, and of a higher resolution than the CAC images, due in large part to the additional filtering techniques. The CAC database, which achieves a 45:1 compression, was developed several years earlier than the CADRG database and was proven in combat situations during Operation Desert Storm. Both databases suffer loss of data during compression, and the actual differences between the images output by the databases are slight.

14. SUBJECT TERMS
requirements, MC&G data, mapping, DCW, ADRG, WVS

15. NUMBER OF PAGES
16

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Same as report

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

CONTENTS

A COMPARISON OF THE COMPRESSED AERONAUTICAL CHART AND COMPRESSED ARC DIGITIZED RASTER GRAPHICS COMPRESSION TECHNIQUES FOR ARC DIGITIZED RASTER GRAPHICS COMPRESSION

1.0 INTRODUCTION

The Defense Mapping Agency (DMA) is currently considering an additional compressed database based on the standard DMA database, Equal Arc-second Raster Chart (ARC) Digitized Raster Graphics (ADRG), as its source. The Navy Standard Compressed Aeronautical Chart (CAC) Database, approved in August 1991, achieves a 45:1 compression and is currently the only standard compressed ADRG database. The more recent Air Force Compressed ARC Digitized Raster Graphics (CADRG) prototype database, developed by the Air Force and MITRE Corporation and submitted in July 1993, achieves a 55:1 compression. The purpose of this investigation, performed by the Naval Research Laboratory's Digital Mapping, Charting, and Geodesy Analysis Program (DMAP), is to examine the compression techniques employed by each of these databases and to evaluate their relative effectiveness in producing quality compressed images. DMAP is sponsored by the Oceanographer of the Navy, NO96, and is responsible for performing the Navy technical reviews of all emergent digital mapping databases and standards.

1.1 ARC Digitized Raster Graphics

ADRG is designed to be a worldwide, seamless data set of digital images. Individual ADRGs are created by scanning source maps at a scan density of 100 microns and transforming the digital images into the ARC projection (tiling) system. The scanned-chart images are then stored on compact disk-read only memory (CD-ROM) and distributed by the Defense Mapping Agency (DMA). A typical hard copy source map is approximately 3′ by 5′ and, when digitized, can require almost 400 megabytes (MB) of storage space (Southard 1991). A maximum of 600 MB can be safely stored on a single CD-ROM, so use of raw ADRG data is currently both impractical and costly in terms of storage. Consequently, compression databases seek to minimize storage requirements while maintaining high image resolution.

1.2 Compression Overview

Three basic steps of compression are utilized by both CAC and CADRG: spatial downsampling, color compression, and spatial compression (Fig. 1). The databases use different algorithms to implement these steps, and as a result, achieve different compressions. The CADRG database also uses certain filters (described later) that do not affect the compression, but serve to enhance the quality of the resultant compressed images. Because of these differences between the databases, the quality and resolution of the final decompressed images vary.

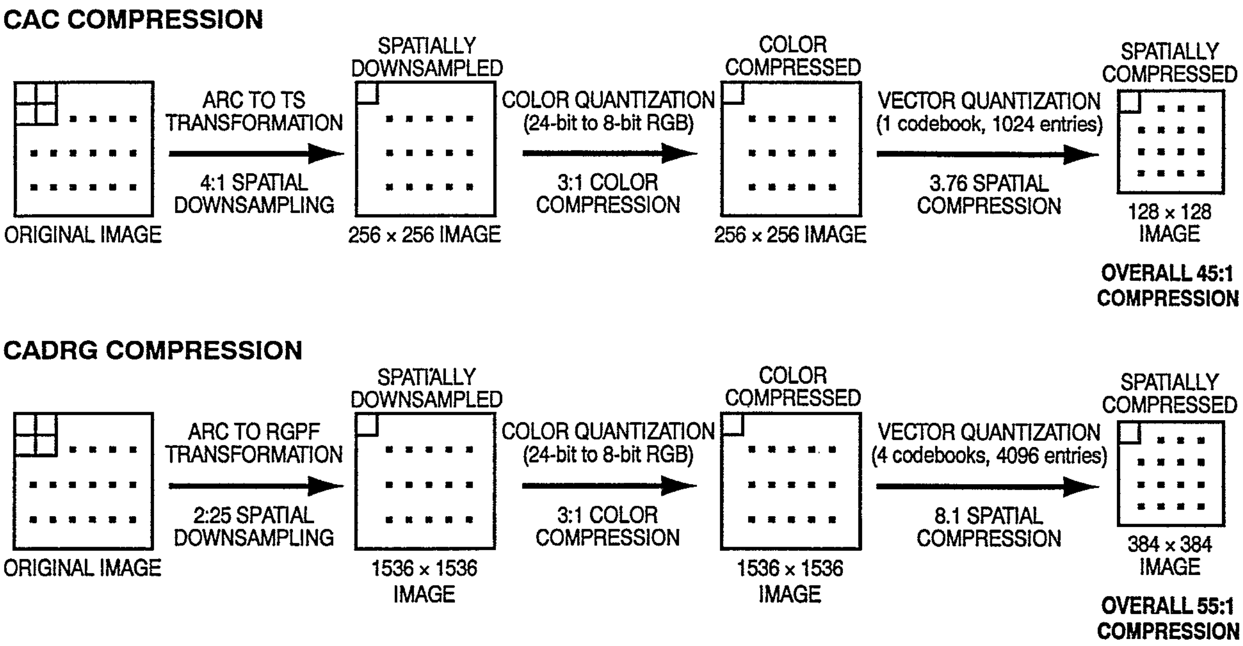

Fig. 1 — Comparison of CAC and CADRG compression

1.3 Purpose

The purpose of this report is to compare two DMA databases of compressed ADRG data, with a focus on the algorithms used to implement the compressions for each database. Image quality is also discussed, and sample images from each database are given.

2.0 SPATIAL DOWNSAMPLING

Spatial downsampling is the process of reducing the amount of data to be compressed by decreasing the number of pixels in a data set. For both databases, the ADRG images are transformed into alternate projection systems. Original ADRG data are transformed into the tessellated spheroid (TS) projection in the CAC database, and transformed into raster product format (RPF) in the CADRG database. These transformations are not without loss, since a decrease in resolution results from fewer pixels being present.

Before proceeding with a study of the alternate projection systems, it is important to be familiar with the ARC projection system. This system provides a rectangular coordinate system for the entire ellipsoid model of the earth based on the 1984 World Geodetic System. The ellipsoid is divided into 18 bands of latitude, two of which cover the polar regions. The other 16 bands are bounded by latitude limits and encircle the entire ellipsoid. Each band, or zone, is then organized into sections, called tiles, the number of which depends on the scale of the source map (Defense Mapping Agency 1989).

The transformation from the source map into ARC zones introduces a slight distortion to the data. For each nonpolar zone, distortion occurs as a shrink near the equator or a stretch near the pole. The stretch or shrink of an area does not exceed 18% except in overlap areas, where the stretch is less than 25%. For the polar zones, distortion from the projection is less than 10% (Defense

Mapping Agency 1989). Additional distortion caused by the transformation from the ARC projection system into an alternate projection system will be discussed in the following sections.

2.1 ARC to TS Transformation (CAC)

In the Navy CAC database, all original ADRG data are transformed into the TS projection system. This projection system, developed at Honeywell, Inc., divides the earth into five latitudinal bands (Lohrenz and Ryan 1990). There are two polar zones, two temperate zones, and an equatorial zone. Each zone is divided into spherical rectangular segments. Each of these 256- × 256-pixel segments is stored as a single CAC image file. Segment size remains constant, but the geographic coverage per segment varies by map scale. The TS system uses only six different map scale models.

The actual ARC to TS transformation employs a neighborhood averaging function. Original ADRG data have a pixel density of 254 pixels per inch (100 mm), and pixel density in the TS system is 128 pixels per inch (scan interval ≈ 200 μm) (Lohrenz and Ryan 1990). Hence, for a particular pixel location in the TS projection system, there are four pixels in the ARC system that are very near, but not necessarily equal to, that pixel location. For each pixel location in the TS system, perform the transformation by finding the average of the four nearest pixels in the ARC system that correspond to that pixel location. The average of the four pixel values becomes the data value in the TS pixel location. The transformed pixels are then organized into segments. The width and height in degrees of a segment is constant within each zone, and for each zone there is an overlap of a total of 1024 pixels. Distortion occurs during equal-area projection of CAC data, but this distortion is extremely small in most regions. The overall distortion is very close to the ARC distortion levels. *A 4:1 spatial reduction results from performing this transformation over the entire image.*

2.2 ARC to RPF Transformation (CADRG)

The Air Force CADRG database uses the RPF as its projection system. The zone limits for this system are the same as for source ADRG data, although the segment size and pixel density differ. Pixel density in the RPF system is 169 pixels per inch (150 μm). The major difference between the two systems is that the RPF system has uniform pixel intervals and constant frame size for each scale source product. Each frame forms a rectangular array of 1536 × 1536 pixels and is tiled into a grid of 6 × 6 subframes. Each subframe is therefore an array of 256 × 256 pixels and represents a single CADRG image.

The first step in the ARC to RPF transformation is to determine the north-south pixel constant or the number of latitudinal pixels from the equator to a pole (Defense Mapping Agency 1993). The "B" parameter is the pixel-spacing constant for ADRG data at the 1:1M scale. The ADRG pixel-spacing constant for a 1:S scale (S is a given constant; e.g., 1:2M, so S=2) is found by multiplying the B parameter by 1M/S and rounding the product to the next highest multiple of 512 pixels. To find the CADRG north-south pixel constant, divide the ADRG pixel-spacing constant by (4*150 μm)/100 μm and round to the nearest multiple of 256 pixels. Once this constant is found, the CADRG north-south pixel size can be determined by multiplying the ADRG pixel size by the ADRG pixel-spacing constant, and dividing by four times the CADRG north-south pixel constant. The east-west pixel constant, or the number of longitudinal pixels from the 180° west meridian moving eastward along the zone midpoint is found as well, and the east-west pixel size is determined. Some additional computations are also required for the polar zone pixels. For more details on this process, consult the draft CADRG Military Specification MIL-C-89038 (Defense

Mapping Agency 1993a). Since the CADRG pixel constants are rounded to the nearest multiple of 256 pixels, an integral number of subframes can be created. Also, since pixel spacing is uniform, frame size is constant. The utilization of constant frame size allows for easy display and direct use in an aircraft cockpit. For each zone there is a total overlap with neighboring zones of 1024 pixels. Distortion caused by this transformation is negligible (Defense Mapping Agency 1993). *Overall, this transformation results in a 2.25:1 spatial reduction.*

2.3 Spatial Downsampling Conclusions

As a result of spatial downsampling, both databases have fewer data values and a more organized format. The CAC TS projection system is advantageous in that it succeeds in a greater spatial reduction. Also, since the number of zones is reduced to five, fewer color tables are needed. However, more spatial reduction also means more loss in resolution, and larger zones mean more area must be covered by each color table. This has both advantages and disadvantages, which will be discussed later. The CADRG RPF projection system results in a smaller spatial reduction, which means less of a change in resolution. Also, decompressed images remain in the alternate projection system format resulting in 2.25:1 versus 4:1 spatial reduction, so decompressed CADRG images appear to be about two times larger than CAC images (Figs. 2 and 3). The main advantage of the spatially downsampled CADRG data is its more organized format. Note that the overlap between zones for both databases has the same number of pixels. Since the CADRG database has more zones, there is also more redundancy due to this zone overlap. Except for size, the CAC and CADRG spatially downsampled images are not much different in visual appearance.

3.0 FILTERING TECHNIQUES

The loss in resolution that occurs due to spatial downsampling can be reduced through the use of filtering techniques. Of the two databases examined in this study, only the CADRG database currently uses filters to enhance the image resolution.

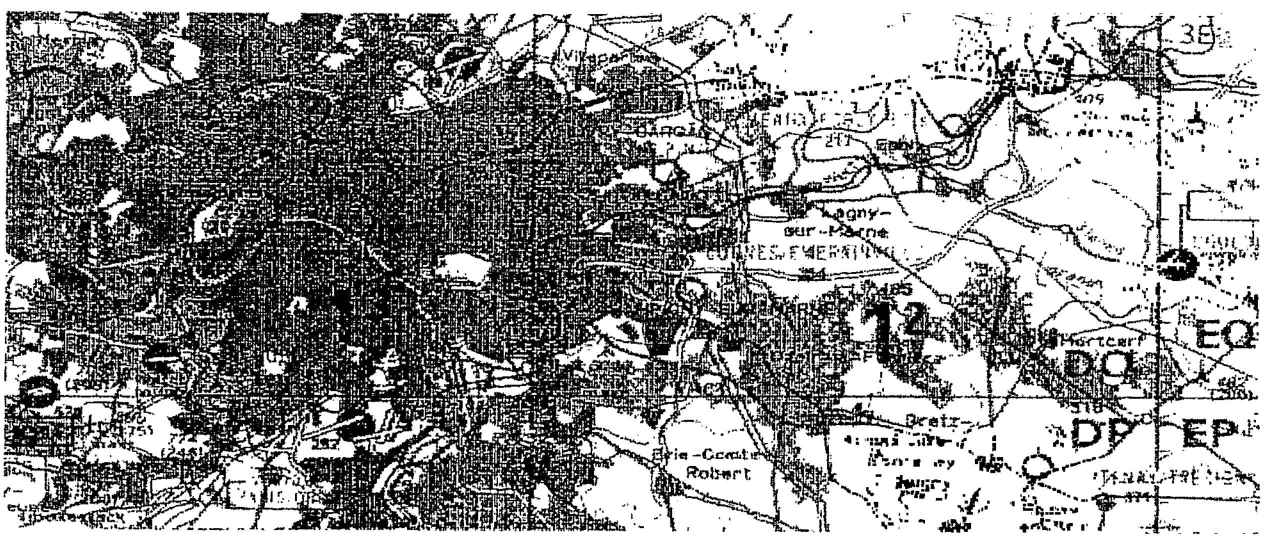

Fig. 2 — Decompressed CAC image of Paris, tactical pilotage chart, 1:500,000 scale

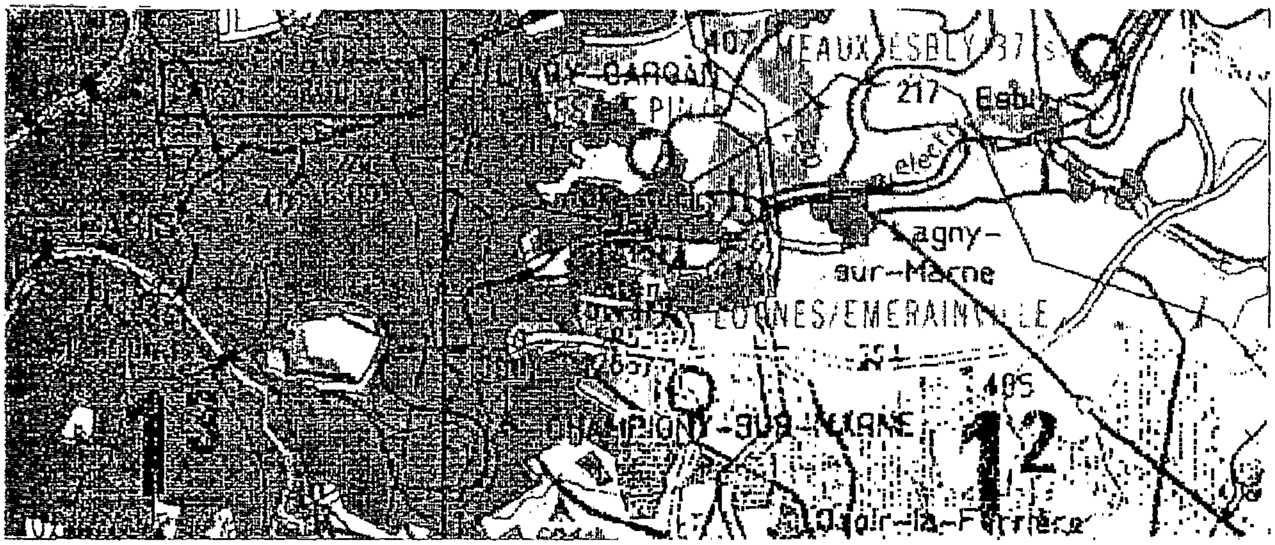

Fig. 3 — Decompressed CADRG image of Paris, tactical pilotage chart, 1:500,000 scale

3.1 Separable Bicubic Filtering Technique

The first filtering technique employed by the CADRG database is the separable bicubic filtering technique (Defense Mapping Agency 1993). This technique is used for the interpolation and subsampling of data. It also aids in eliminating stipple and moire, which are image defects produced when the original source maps are scanned. Mitchell and Netravali (1988) have explored in detail separable cubic filters, and recommend the bicubic filter given by the equation

$$k(x) = \frac{1}{6}\begin{cases} (12-9B-6C)|x|^3 + (-18+12B+6C)x^2 + (6-2B) & \text{if } |x| < 1 \\ (-B-6C)|x|^3 + (6B+30C)x^2 + (-12B-48C)|x| + (8B+24C) & \text{if } 1 \le |x| < 2\,, \\ 0 & \text{otherwise} \end{cases}$$

where $(B,C)=(1/3,1/3)$ and x is a real-valued variable. They purport that these values for B and C yield the best results. This technique works well on the spatially reduced CADRG data, but another filter is still necessary to enhance the sharpness of the images.

3.2 Unsharp Mask Filter

The unsharp mask filter sharpens or improves local contrast of an image by decreasing the range of brightness of the data. This is accomplished by first blurring, or smoothing, an image and then subtracting this blurred image pixel by pixel from the original image (Russ 1992). This technique has the effect of decreasing the blurring that results from downsampling and the bicubic filter, and increasing the sharpness of the CADRG image.

3.3 Filtering Conclusions

After filtering, the CADRG images appear clearer and more readable. The increased sharpness of the images makes edges more distinct and makes small variations in the data more visible. Since the CAC data concurs a greater spatial reduction and does not implement any filtering techniques, it is concluded that the CADRG data has a slightly better appearance than the CAC data in most regions prior to compression. In some mountainous regions, or regions of varying contours, shading is frequently used to illustrate mountainsides. This type of shading is often distorted in CADRG images by the filtering techniques. Hence, these types of regions are better represented in CAC images.

4.0 COLOR COMPRESSION

Prior to compression, there are 24 bits of color data per pixel in the images, which amounts to a total of over 16.7 million possible colors (Defense Mapping Agency 1993). Since each image zone uses at most a few hundred different colors, color compression would not only greatly reduce the amount of storage required, but would also maintain adequate variability in color choices. The color compression techniques for both databases replace each of the 24 bits of color data (8 bits each of red-green-blue (RGB)) with an index for a single 8-bit color code. Compression reduces the number of possible colors to 256. During decompression, each pixel value in the compressed image is replaced by the 8-bit codeword it indexes in the color palette (Figs. 4 and 5).

4.1 Least-Squares Fitting Technique (CAC)

To perform a color compression for the CAC database, a color quantization process is used that matches an entry from a color palette with each pixel in the spatially downsampled image. First, a color map or palette must be developed. The CAC database uses a different palette for each of the 5 zones of the 6 map scales, for a total of 30 palettes (some of the palettes are identical). All of the images in a particular zone refer to the same color palette, so only one color palette for each zone needs to be stored on CD-ROM. This has the advantage of saving valuable disk space. It can cause problems, however, if there are a wide range of colors for a particular zone and, hence, not enough colors in the color palette to adequately represent the various areas in the zone. The least-squares fitting technique is used to find the 240 RGB combinations which best represent a particular zone of data. The remaining 16 possible colors are used for graphic overlays. Now suppose we have N data points and we wish to approximate the data with a polynomial of degree less than N. We should choose the 240 color combinations which produce the least error based on the RGB data in the image. Once the color palette is developed, the 240 palette entries can be used to compress the image. To color compress the image, each 24-bit pixel of the image is replaced with the closest match of the 240 entries in the palette. Monochrome values are also placed in the color palette and are computed by the equation

$$\text{Mono} = (0.30 \times \text{Red}) + (0.59 \times \text{Green}) + (0.11 \times \text{Blue})\,.$$

The weights in the above equation are standard values used to convert to monochrome. *This technique produces a 3:1 color compression of the image.*

4.2 Pairwise Nearest Neighbor Algorithm (CADRG)

The color quantization technique for the CADRG database involves the pairwise nearest neighbor (PNN) algorithm to find the color table for each zone. Recall that there are 18 zones per map scale.

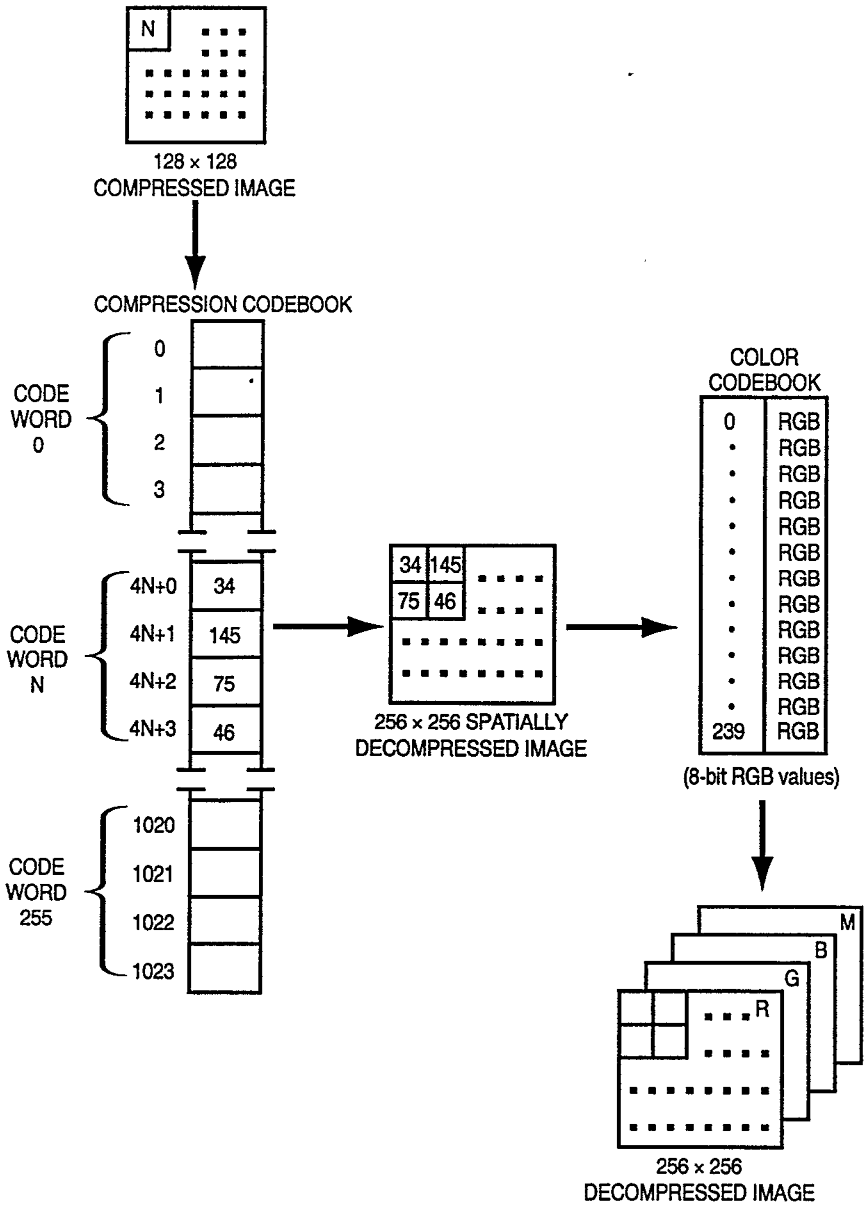

Fig. 4 — CAC decompression

A color palette is stored with each frame file on CADRG CD-ROM, however, rather than for each zone. Each color table is comprised of 216 palette entries of RGB and monochrome values. The remaining 40 colors are used for graphic overlays. To create the desired palette, the PNN algorithm begins with a separate cluster for each training set vector and merges clusters two at a time until only 216 clusters remain. The training set vectors are the 24-bit RGB color combinations in the spatially downsampled CADRG images. Each time two clusters are merged, the codeword of the new cluster becomes the mean of the vectors in the new cluster.

The essential basis for choosing the two clusters to be merged is that the clusters be close and affect few training vectors. Suppose that C_i is the ith cluster of training vectors and n_i is the

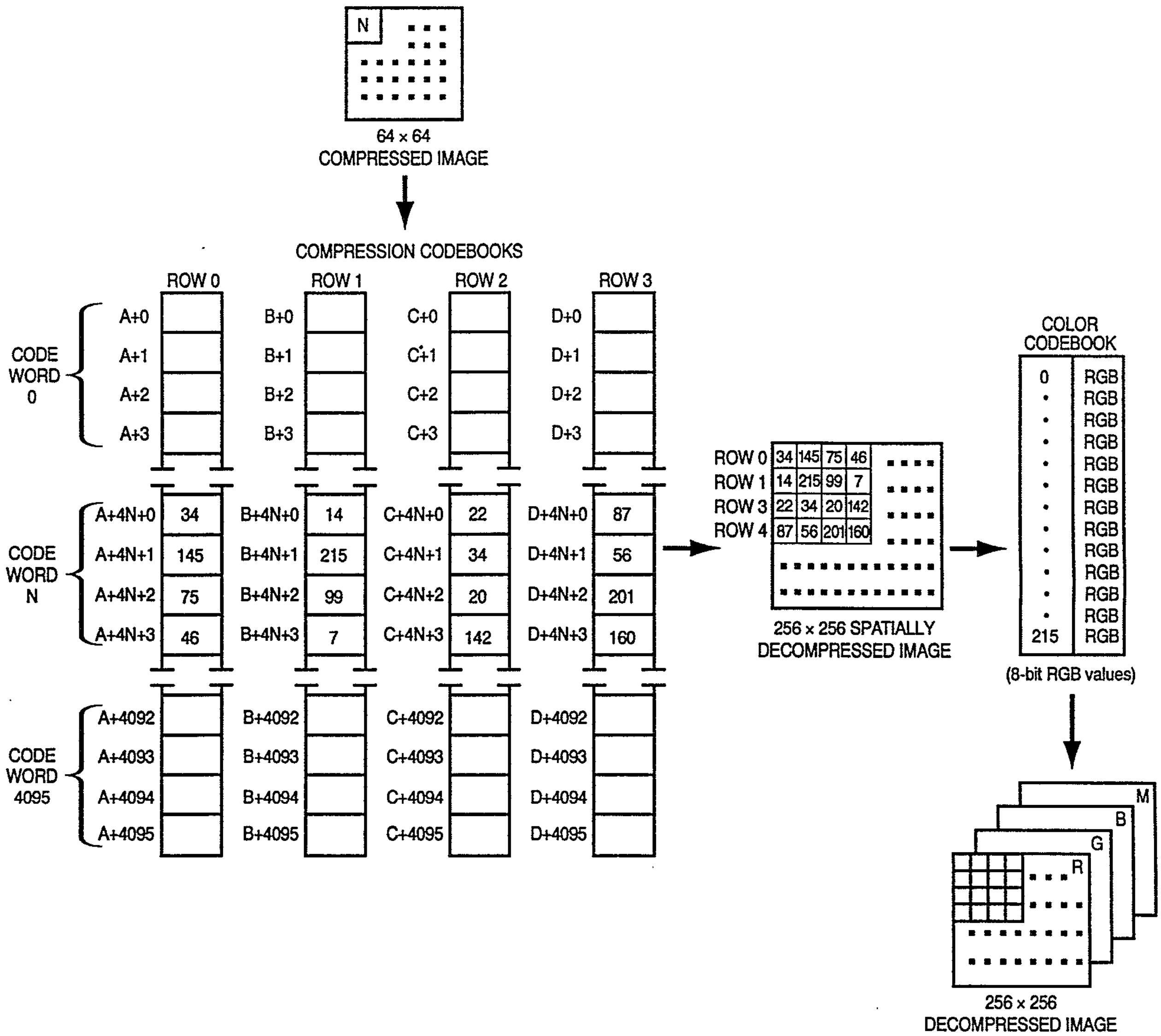

Fig. 5 — CADRG decompression

number of training vectors in C_i. Let x_i be the mean of the training vectors in C_i. Then the squared error, SE, introduced by merging clusters C_i and C_j, the jth cluster, is

$$SE = \frac{n_i n_j}{n_i + n_j} \left| x_i - x_j \right|^2 .$$

The clusters C_i and C_j which minimize this quantity are the ones which should be merged (Equitz 1989).

The color table with 216 8-bit palette entries produced by the PNN algorithm is utilized to color compress the CADRG images in the same way CAC images are color compressed. Each 24-bit RGB combination is replaced by an index for an 8-bit entry in the color palette. Monochrome values are computed and stored in the color palette as well. This technique also succeeds in a 3:1 color compression.

4.3 Color Compression Conclusions

The same amount of color compression is achieved with both databases, although the algorithms used and the size of the color tables are different. The larger color table size of the CAC database signifies that more colors can be displayed, although it also limits the ability for CAC data to be displayed on certain computer systems. For example, many UNIX workstations can only support 216 colors. Hence, a CAC color table must currently be made smaller before images can be displayed on these machines. This alters the appearance and quality of the images. The CADRG database avoids this problem, since the color tables have only 216 entries. A visual comparison of CAC and CADRG images over the same area reveals that the color tables use slightly different shades of colors (Figs. 6 and 7). These differences in shading are mainly due to the different algorithms

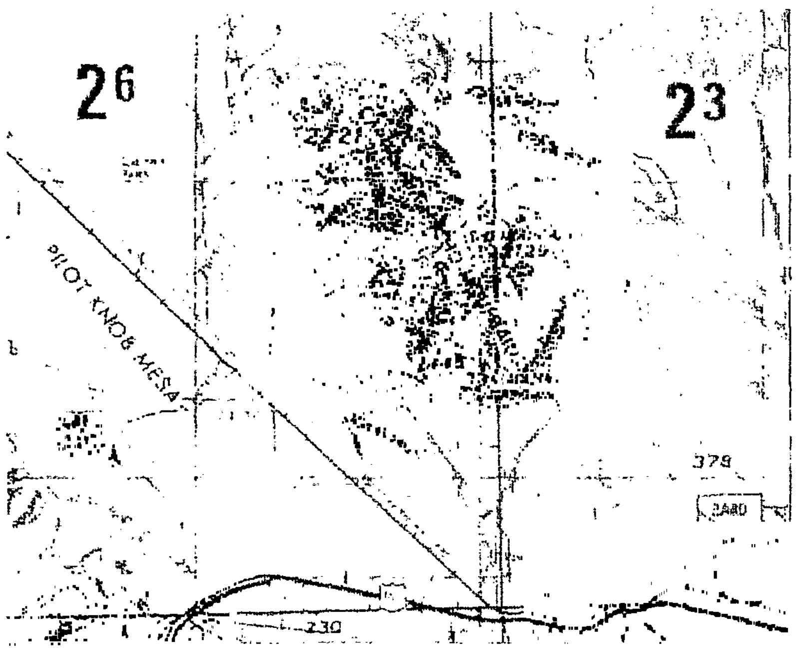

Fig. 6 — Decompressed CAC image of the southwest United States, Joint Operational Graphic Chart (1:250,000 scale)

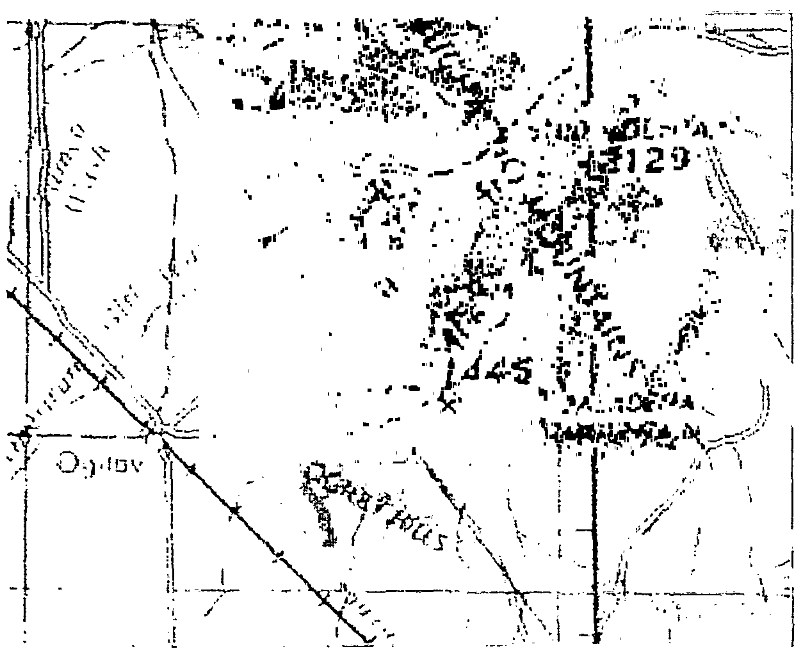

Fig. 7 — Decompressed CADRG image of the southwest United States, Joint Operational Graphic Chart (1:250,000 scale)

used to create the color palettes. Differences due to the size of the palettes is negligible. Overall, the CADRG images appear more vibrant than the CAC images (Figs. 2 and 3). This clarity is probably due more to the filtering techniques than the compression techniques, since the colors of the spatially downsampled CAC images are very similar to the colors of the color compressed CAC images. For the most part, the differences in the quality of the color compressed images are negligible. For one particular area, the CAC image may show more detail than the CADRG image as a result of color choices, whereas the opposite may be true over a different area.

5.0 SPATIAL COMPRESSION

The process of spatial compression for both databases utilizes vector quantization (VQ), similar to color quantization in that a codebook of vectors, which are representative of the image data, is created and indexed in the compressed image frame file. A separate codebook is made for each frame file rather than for an entire zone. The size of the vectors and the size and number of codebooks differs for the two databases.

5.1 CAC Spatial Compression

The CAC database employs a VQ process using 2×2 blocks, or vectors, with a single codebook containing 1024 entries, or 256 codewords, for each image file. To spatially compress, a VQ codebook is developed by classifying the image into 256 vector clusters, which best represent the vectors of the image. Then, each 2×2 block of pixels in the uncompressed image is replaced by an index into the VQ codebook. This produces a compressed image file that is four times smaller than the file prior to the compression (Fig. 1). Including the size of the codebook file, there is a net 3.76:1 spatial compression. Excluding codebook file size, there would be a 4:1 spatial compression and an overall 48:1 compression. However, to make a valid comparison between CAC and CADRG, file size must be included when figuring the spatial compression. For decompression, each pixel in the image file is an integer between 0 and 255, say codeword N. This value N then references bytes 4N+0, 4N+1, 4N+2, and 4N+3 in the codebook. The value at each of these positions is an integer between 0 and 239 and is arranged in a 256×256 output segment matrix, which is ready for color decompression (Fig. 4).

5.2 CADRG Spatial Compression

The CADRG database utilizes a VQ process with 4×4 pixel blocks and four codebooks of 4096 pixels each. Each row of the 4×4 pixel block references a different codebook, and each byte of the codebook contains four color codebook indices. Hence, each 1536×1536 color compressed matrix is reduced to a 384×384 spatially compressed matrix of 12-bit codes (Fig. 1). This is equivalent to a 16:1.5, or 10.66:1, compression. However, due to the size of the compression codebooks, this results in only a net 8.1:1 spatial compression. During decompression, each pixel of the 64×64 compressed 12-bit matrix has a value ranging from 0 to 4095, referencing a particular codeword in each of the four codebooks. To access the color indices associated with a codeword, say N, we first let A be the offset for the beginning of the first compression codebook. Then the indices for the first row of the 4×4 vector in the decompressed image are located at byte positions A+4N, A+4N+1, A+4N+2, and A+4N+3. The indices for the second row of the vector would be offset 16,384 bytes from A (B=A+16,384), and rows three and four would be offset 32,768 bytes and 49,152 bytes, respectively (let C=A+32,768 and D=A+49,152). The 256×256 8-bit matrix that results can then be color decompressed for viewing purposes (Fig. 5). Note that for the CADRG database the codebooks are created per frame, but the data is decompressed per subframe.

5.3 Spatial Compression Conclusions

The differences between the spatial compressions for the two databases are shown clearly by examining the spatial decompression charts in Figs. 4 and 5. As illustrated, the CADRG spatial compression technique uses four times as many codebooks, four times as many bytes in each codebook, and results in over two times as much in compression. The benefits are that the loss of data is smaller and that the compression is greater. The larger codebook size requires more storage space in the compression file, but the net gain in spatial compression eliminates its significance. The CAC spatial compression is more simplistic than the CADRG compression, but results in less compression. It is important to note, however, that both of the databases produce decompressed images that show signs of data loss. This is especially noticeable when examining text in the images. In Figs. 6, 7, and 8, notice the differences in readability of the words *Pasadena Mountain* in the lower right corner of each image, as well as other text in the three images. As shown, both CAC and CADRG image text is sometimes hard to read when compared to the original ADRG image text (or the paper map) due to the loss of data in spatial compression. The actual difference between the two decompressed images, however, such as in Figs. 6 and 7, is extremely slight. The main difference is in the size of the decompressed images, as noted earlier. Even in problematic, or "busy," areas, such as in Figs. 2 and 3, the two decompressed images are of approximately the same quality.

6.0 CONCLUSIONS

The two compressed ADRG data sets are similar in the format of their compressions, yet different in the specific algorithms that implement their compressions. The algorithms for the Navy CAC database produce 45:1 overall compressed images, not 48:1, since the size of the codebook must be considered when determining the compression. The algorithms for the Air Force CADRG database produce 55:1 overall compressed images. By comparing decompressed images for each database over the same area, one can see that the CADRG database output images show more

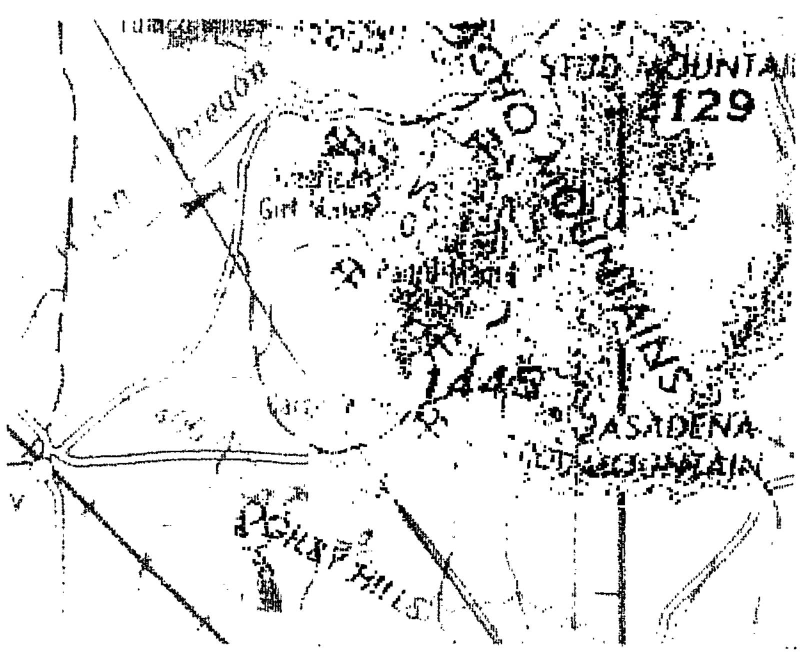

Fig. 8 — Uncompressed ADRG image of the southwest United States, Joint Operational Graphic Chart (1:250,000 scale)

detail and have better resolution. The improvements in image quality, however, are only slight. After spatial downsampling, CADRG images have better resolution because less data are lost. Both CAC and CADRG images exhibit some loss, though, and at the same time they both maintain much image detail. The results from color compression for the two databases are basically the same, although the CADRG database has the advantage of sharper, clearer images and, hence, more vibrant colors due to the filtering techniques. Finally, the differences in image quality between the two databases are increased by spatial compression, since the process used by the CADRG database results in less data loss and a larger compression. It is important to note that the final images output by the databases do not differ greatly, although the CADRG images are of somewhat higher quality. Also, the CAC database has been proven in combat situations since it was used in Operation Desert Storm, while CADRG is still in the prototype stage.

Given the inherent losses in both CAC and CADRG images and the slight overall image quality difference, it is not clear that an additional compressed ADRG database is justified. The CADRG database is a slight improvement over the CAC database in many ways, but this slight improvement is not a quantum normally seen in new products. There remains certain areas where the CAC database is superior. For example, subtle changes in colors and shading, such as in mountainous regions, are more noticeable. Distinctions between roads and rivers are often clearer in CAC images as well, due to color choices. Another consideration is that the current trend in digital mapping is toward vector databases instead of primarily raster, although raster will still be required for certain applications. Given this trend, the necessity of a somewhat better raster database should be questioned.

7.0 RECOMMENDATION

It is recommended that a cost analysis be performed on adding CADRG to DMA's product line. This cost analysis should include impact on all services, especially Navy aircraft digital moving map systems. The cost of implementation, as well as justification for this product, must be taken into account in the decision to implement CADRG.

8.0 ACKNOWLEDGMENTS

This work was supported by the Oceanographer of the Navy, NO96, Harry Selsor, program manager, under Program Element number 0603704N. Thanks are extended to Marlin Gendron, Maura Lohrenz, Mike Trenchard, and Lance Riedlinger for their advice and contributions of data from the CAC database, and Nancy Markuson of the MITRE Corporation for information about the CADRG database and the sample CADRG data.

Technical review of this report was provided by Ms. Maria Kalcic of the NRL Mapping Sciences Section, and by Mr. Mike Harris of the NRL Mapping, Charting, and Geodesy Branch.

9.0 REFERENCES

Defense Mapping Agency Report MIL-C-89038, (DRAFT), "Military Specification: Compressed ARC Digitized Raster Graphics (CADRG)," Fairfax, VA, July 1993.

Defense Mapping Agency, DMA Systems Center/West Group, First Edition, "Product Specifications for ARC Digitized Raster Graphics (ADRG)," St. Louis, MO, April 1989.

Equitz, W. H., "A New Vector Quantization Clustering Algorithm," *IEEE Transactions on Acoustics, Speech, and Signal Processing* **37**(10), 1568–1575 (1989).

Lohrenz, M. C. and J. E. Ryan, "The Navy Standard Compressed Aeronautical Chart Database," NOARL Report 8, Naval Research Laboratory, Stennis Space Center, MS, 1990.

Mitchell, D. P. and A. N. Netravali, "Reconstruction Filters in Computer Graphics," *Computer Graphics* **22**(4), 221–228 (1988).

Russ, J. C., *The Image Processing Handbook* (CRC Press, Inc., Boca Raton, FL, 1992).

Southard, D. A., "Compression of Digitized Map Images," Tech. Rep. MTR-11201, MITRE Corp., Bedford, MA, 1991.

BIBLIOGRAPHY

Defense Mapping Agency Report MIL-STD-2411 (DRAFT), "Military Standard: Raster/Gridded Product Format (RGPF)," 1993.

Hamming, R. W., *Digital Filters*, Second Edition (Prentice Hall, Inc., Englewood Cliffs, NJ, 1983), pp. 33–37.

Lohrenz, M. C., "Military Specification: The Navy Standard Compressed Aeronautical Chart (CAC) Database," SP 024:351:91, Naval Research Laboratory, Stennis Space Center, MS, 1991.